Design and Modeling of a Variable Heat Rejection Radiator

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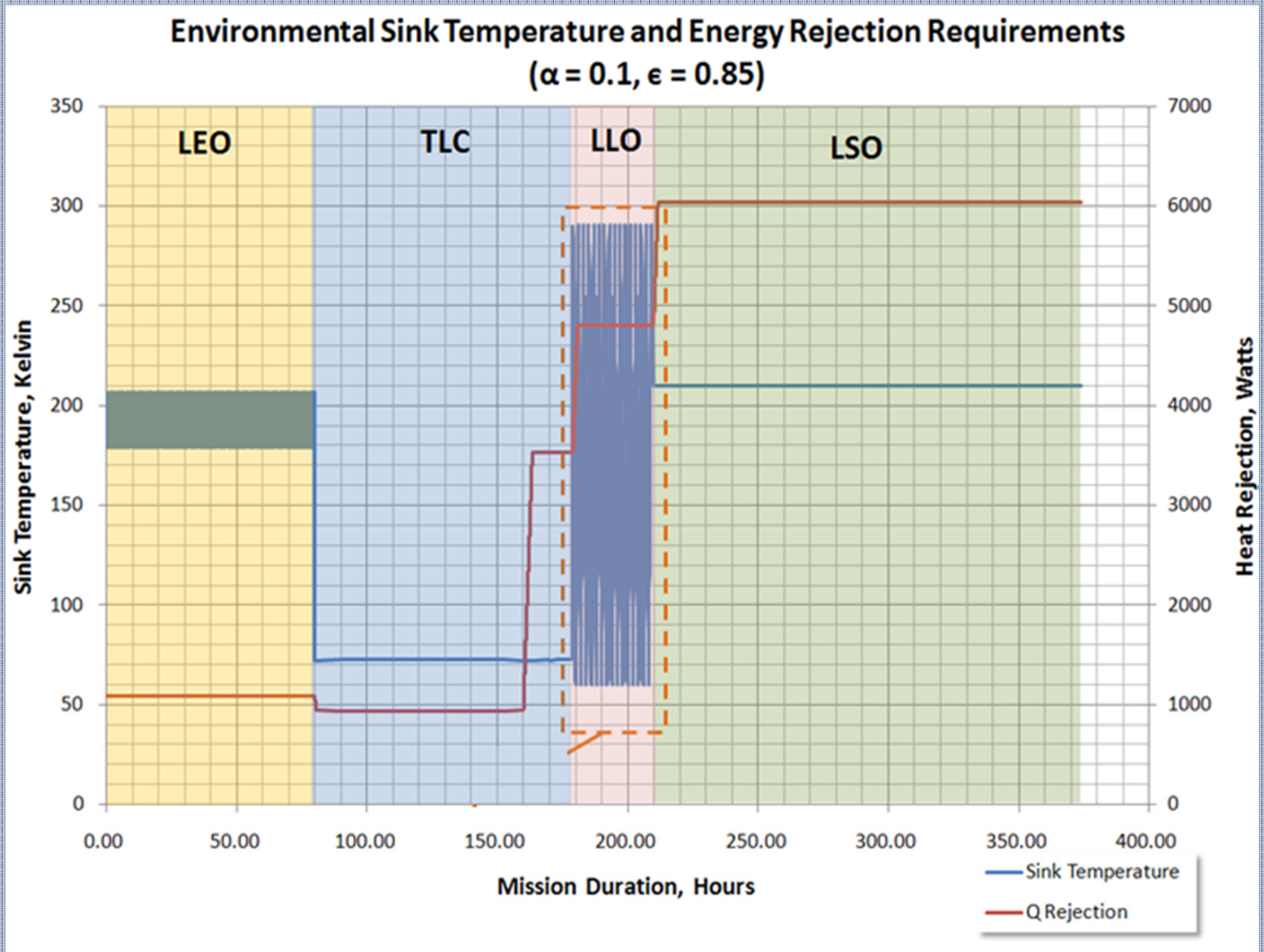
Background

- Variable Heat Rejection Radiator technology needed for future NASA human rated & robotic missions

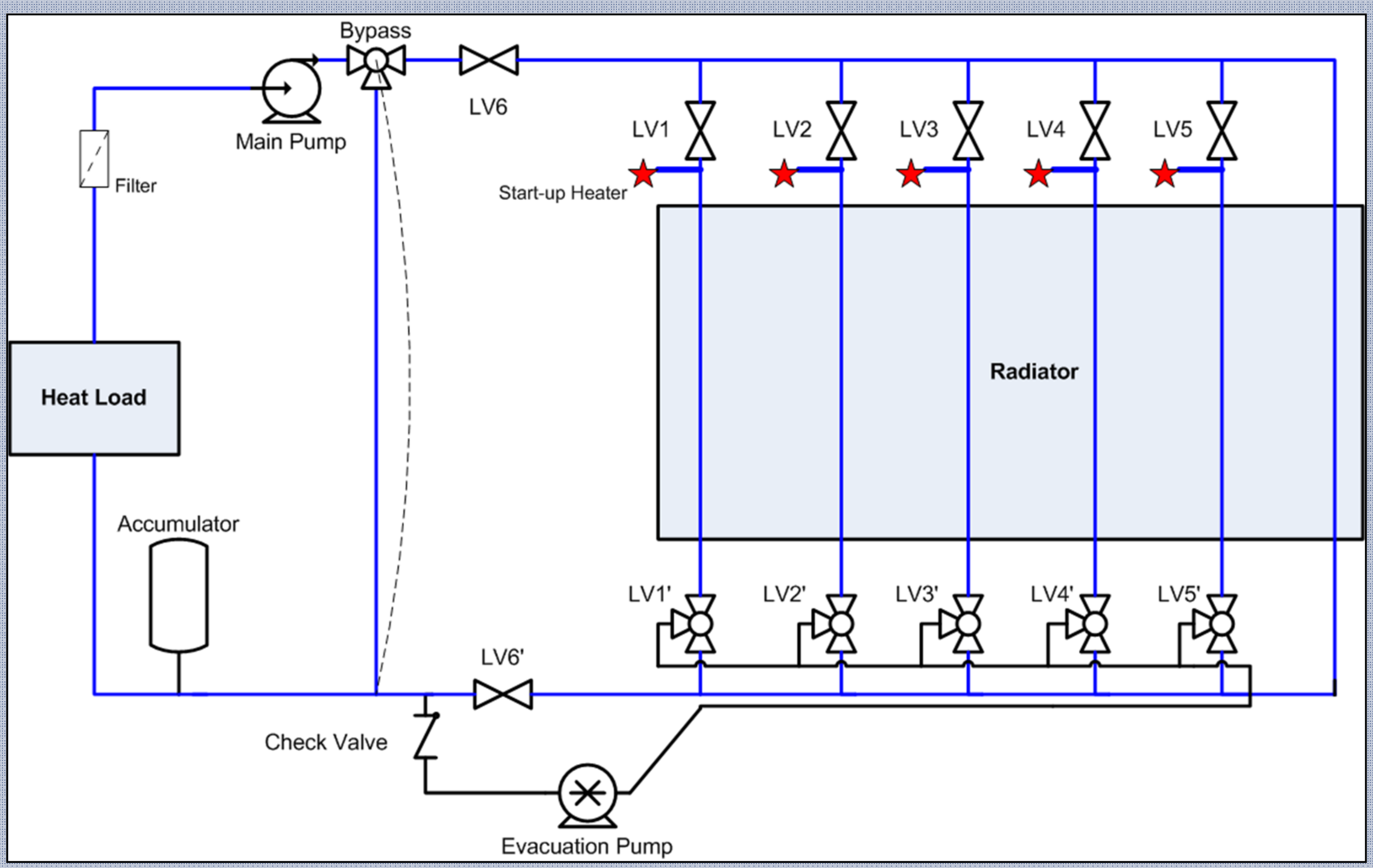
- Primary objective is to enable a single loop architecture for human-rated missions
  - Radiators are typically sized for maximum heat load in the warmest continuous environment resulting in a large panel area
  - Large radiator area results in fluid being susceptible to freezing at low load in cold environment and typically results in a two-loop system
  - Dual loop architecture is approximately 18% heavier than single loop architecture (based on Orion thermal control system mass (09ICES-0353))
  - Single loop architecture requires adaptability to varying environments and heat loads

Example Mission Profile



*Time-Averaged

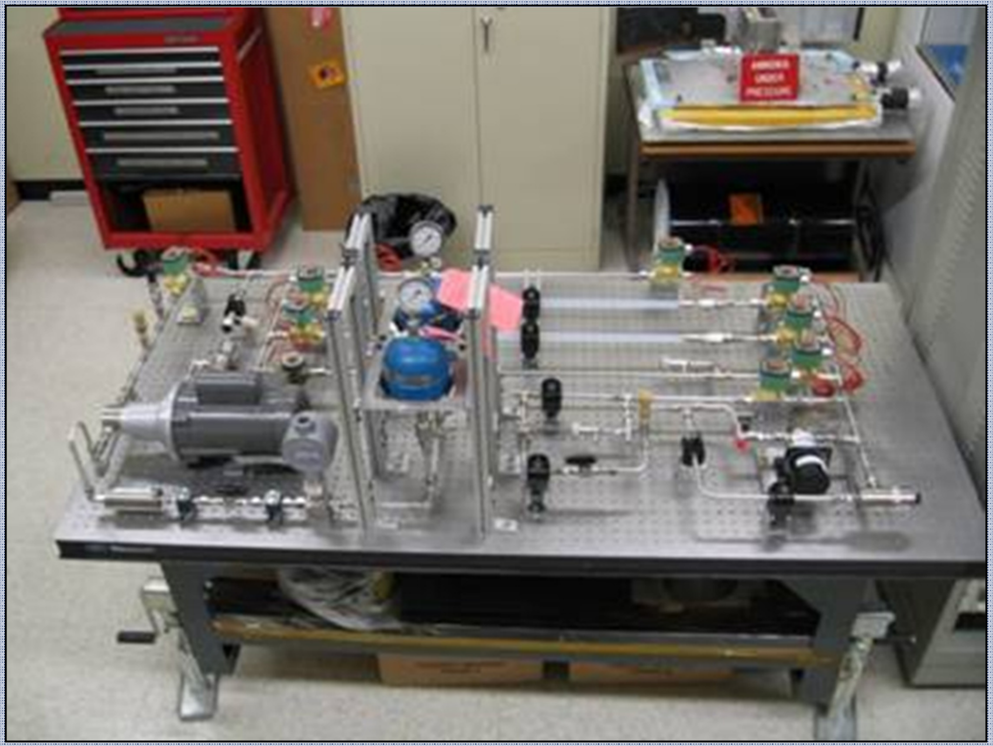
Digital Radiator Concept



Digital Radiator Concept

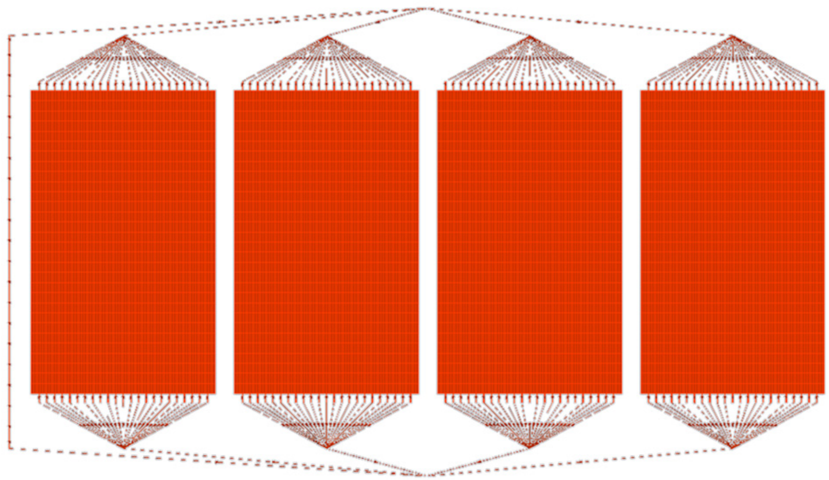
- The concept is based on using valves to turn ‘on’ or ‘off’ the fluid flow through parallel fluid lines imbedded in the radiator
- Extensive analytical work was performed using Thermal Desktop/Fluint to investigate the feasibility of this concept
- Several bench-top tests were performed to verify the fluid evacuation from closed tubes and to verify circulation in the tubes after they have experienced temperatures below the fluid freeze point
- Several fluids were investigated to understand performance
- Based on results from test and analysis, a scaled Digital Radiator design will be developed and tested

Digital Radiator Concept Tests

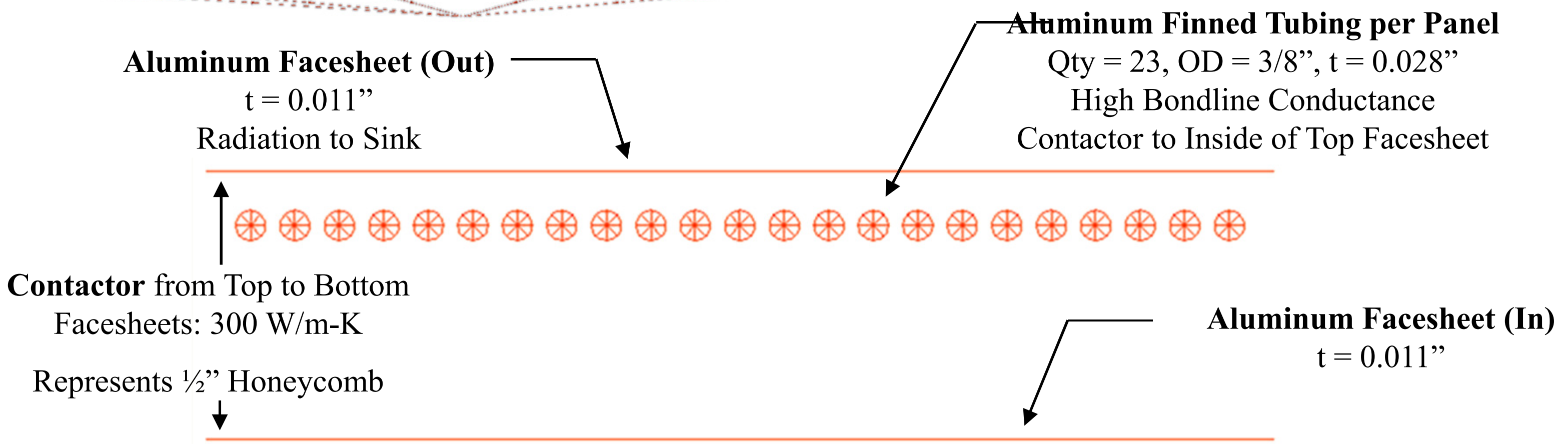


- Bench top testing performed early on for proof of concept (2006-07)
- Results fed into further testing and thermal model development (2008-10)

Thermal Model Description



Four panels of 2m x 3m in parallel with bypass line.



Future Improvements: Non-infinite bondline, transient cases, control feedback loop, pressure drop concerns

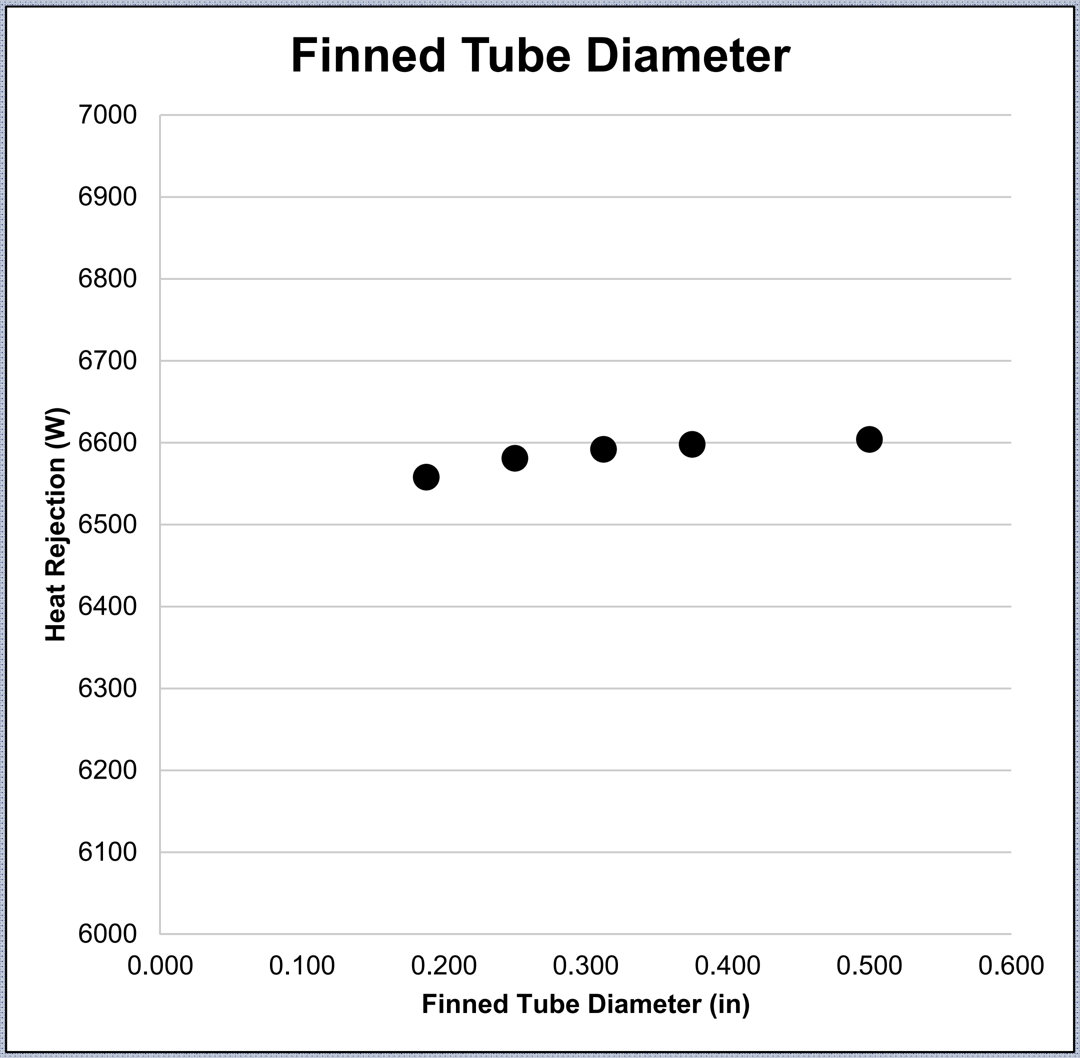
Key Model Assumptions

- Working fluid is 50/50 PGW
- Manifold designed to provide equal mass flow to each tubing segment
- Requirements time-averaged over specific portions of the mission profile
- Bypass line completely insulated
- Embedded tubing thermally shorted to front panel

Trade Space

Traded Parameters	**Performance Parameters**	**Constants**	**Final Configuration**
Radiator Area Tube Diameter Tube Quantity	- Outlet Temperature - Heat Rejection - Overall Mass	Radiators - 4 Radiators - Al 6061-T6 - Facesheets, 0.011” Thick - Al Honeycomb Core, ½” Thick - 10-mil Silverized Teflon Coating - Embedded Tubes Tubing - Finned - Al 6061-T6 - Even Spacing - 0.028” Wall	Radiators - Area - Mass Tubing - Quantity - Diameter - Orientation Fluid - Mass Flow
Tube Orientation Fluid Mass Flow	- Outlet Temperature - Heat Rejection		

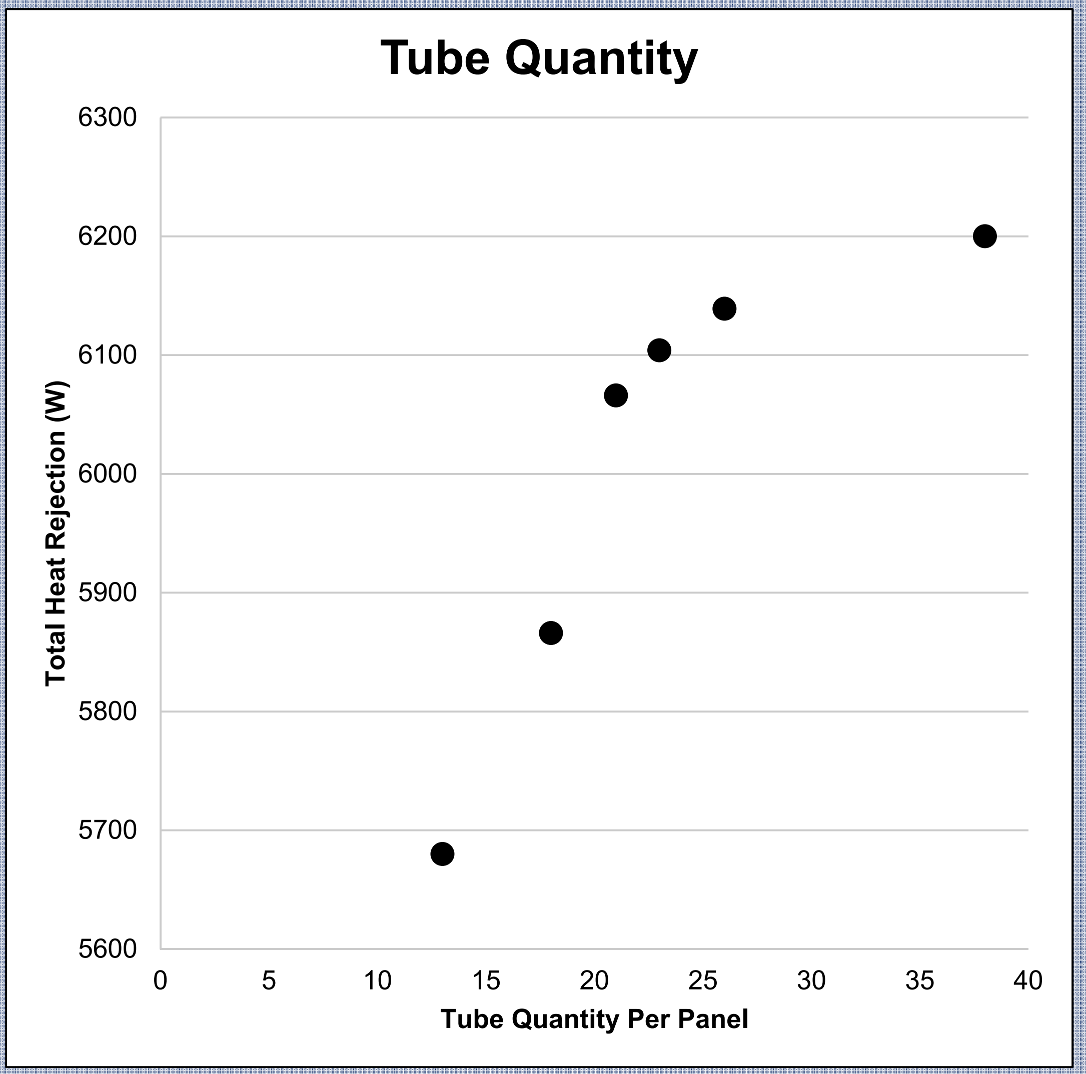
Tube Diameter Study



- No significant increase in heat rejection found for various tube diameters
- Evacuation shown to work in tests on 3/8" tubing

*23 Finned Tubes, 2m x 3.3m Panel, 205K Sink, 0.058kg/s Mass Flow

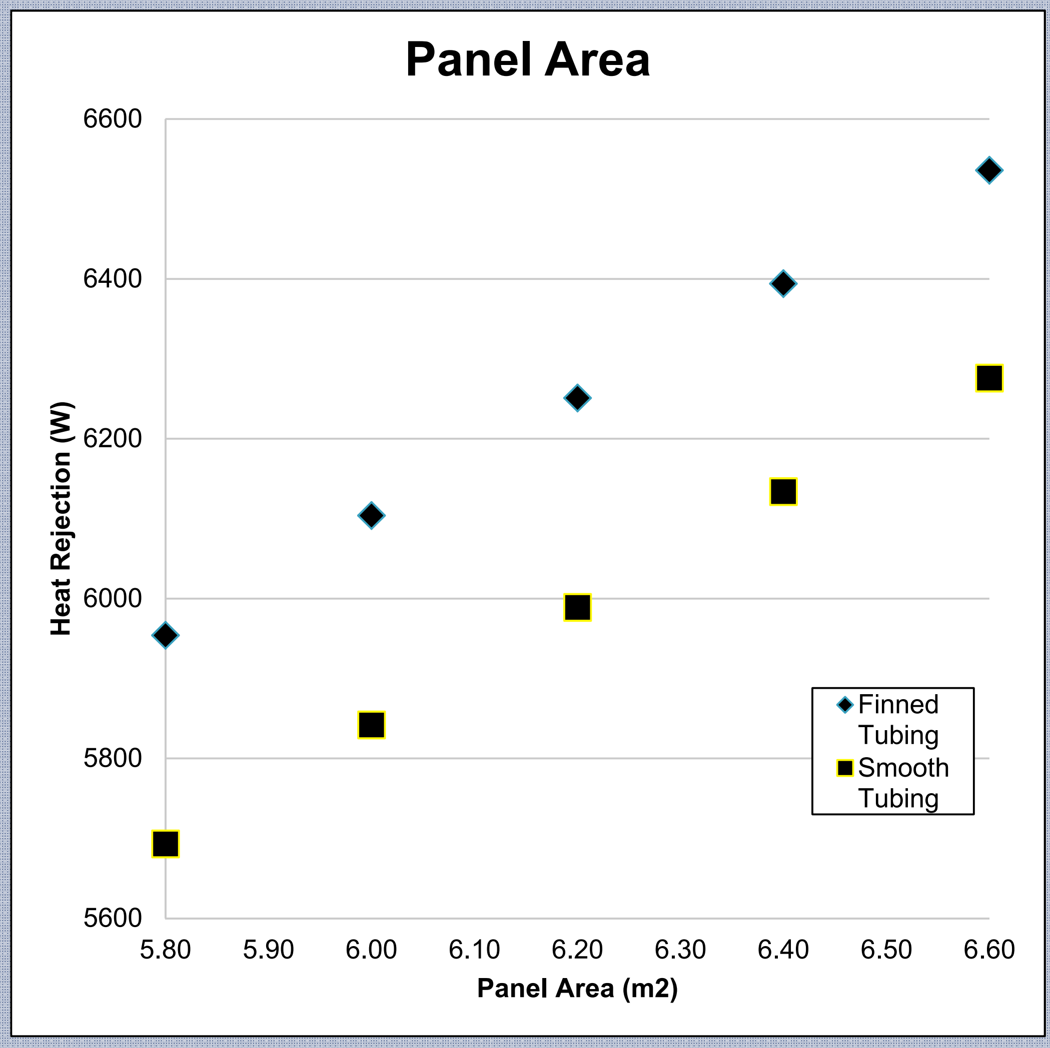
Tube Quantity Study



- Increase in tube quantity per panel results in an increase in heat rejection due to fin efficiency
- A “knee” occurs at approximately 23 tubes
- Tube quantity and associated fluid found to have significant effect on mass

*Finned Tubes, 2m x 3m Panel, 210K Sink, 0.06kg/s Mass Flow

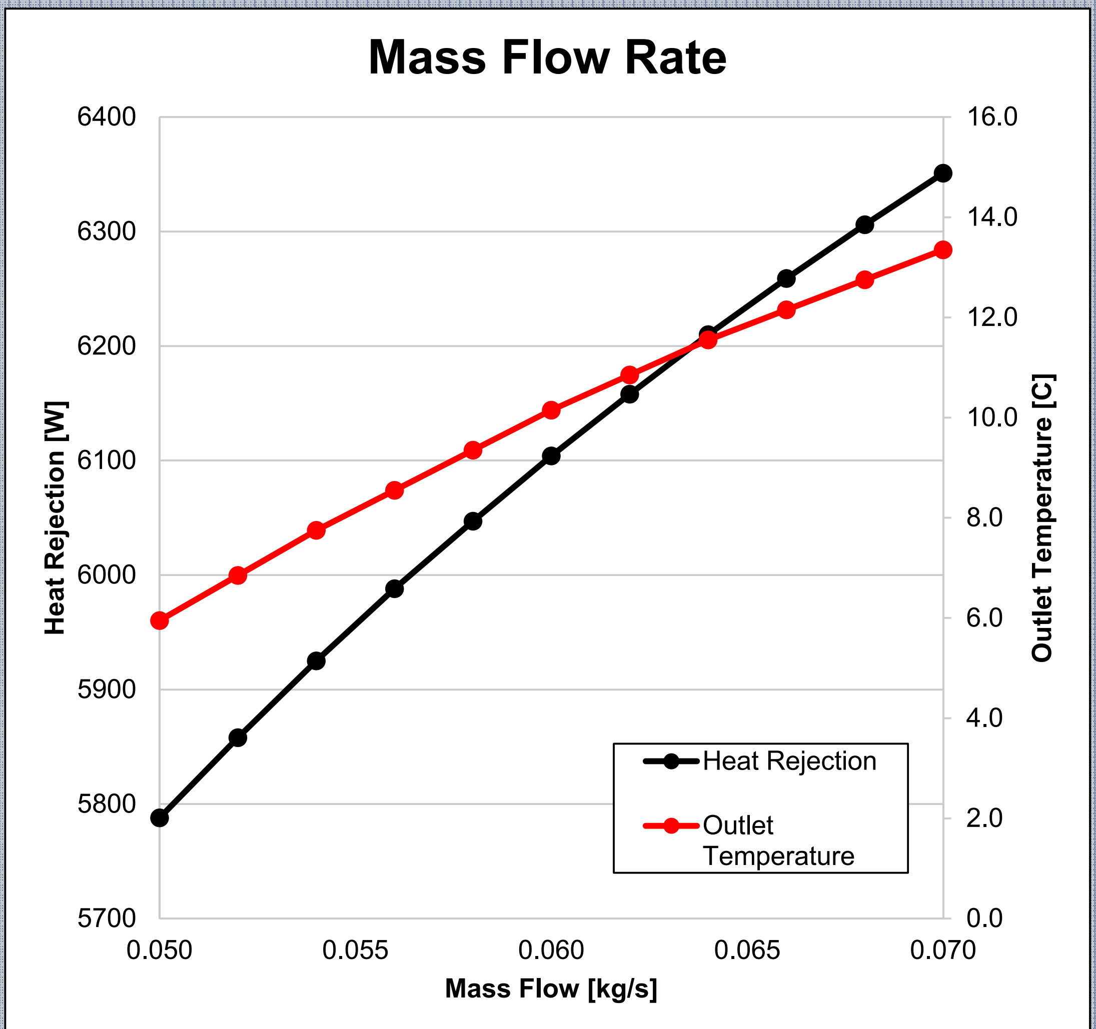
Panel Size Study



- Data shown for internally finned and smooth wall tubing
- Finned tubing shows increase in heat rejection
- Panels sized for LSO (worst case hot). A panel size of $6m^2$ (2m by 3m) is shown to reject the required minimum of 6040W to a 210K sink.

*23 Finned/Smooth Tubes, 210K Sink, 0.06kg/s Mass Flow

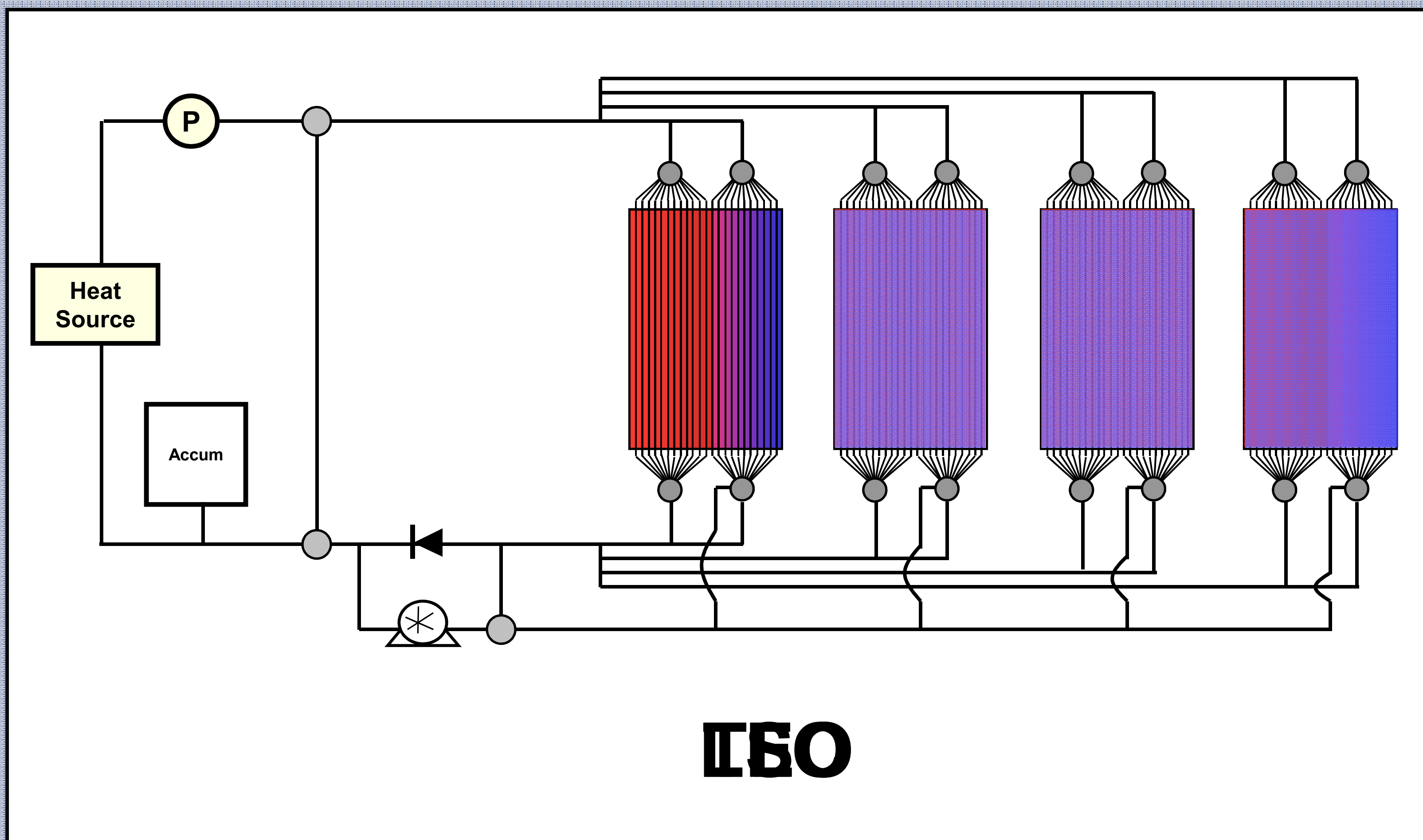
Mass Flow Study



- An increase in mass flow results in an increase in heat rejection as well as an increase in outlet temperature
- A mass flow of 0.06kg/s provides maximum heat rejection while meeting the 10C desired outlet temperature for cabin feedback

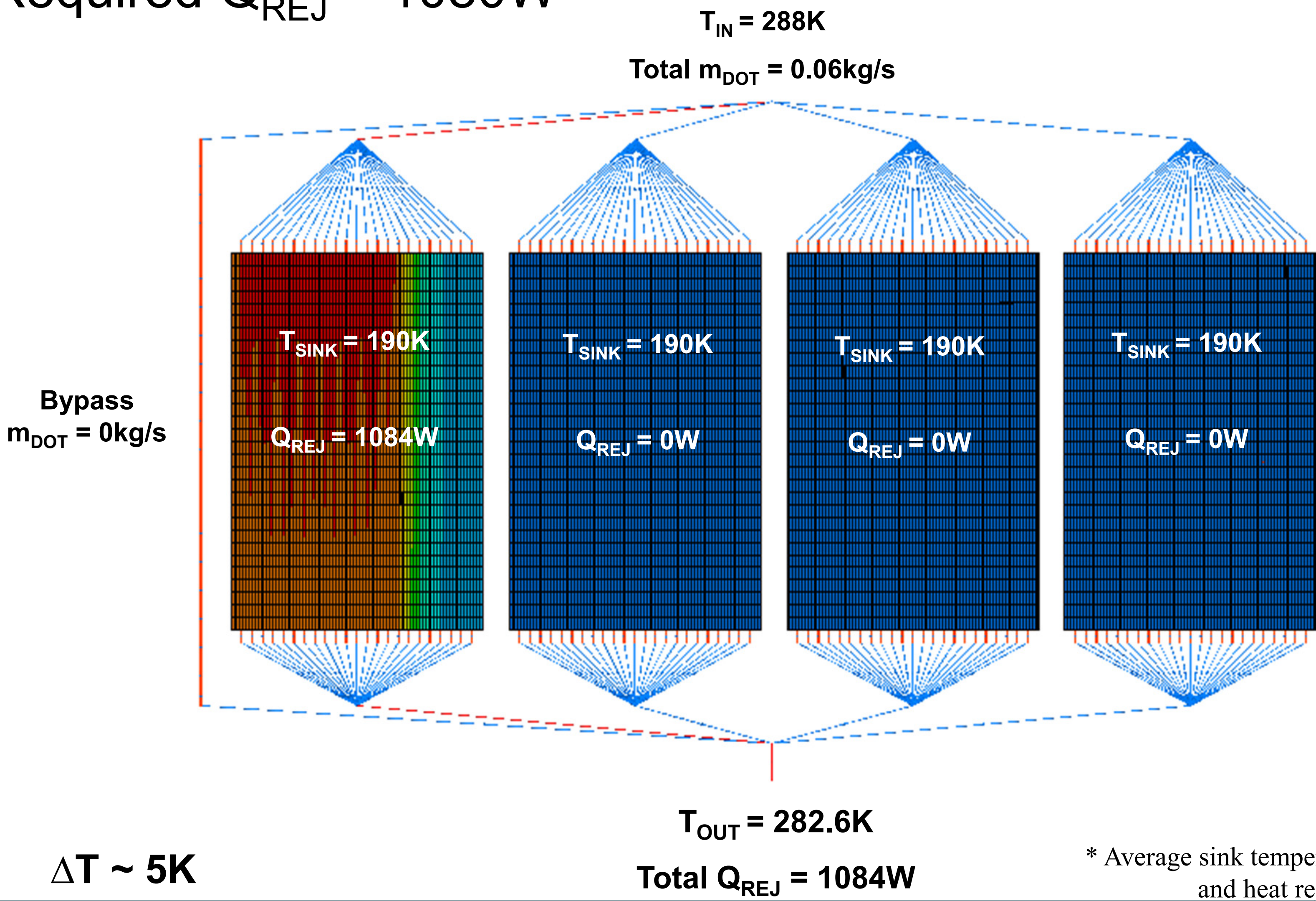
*23 Finned Tubes, 2m x 3m Panel, 210K Sink

Mission Profile



Mission Profile: LEO

Required Q_{REJ} = 1080W

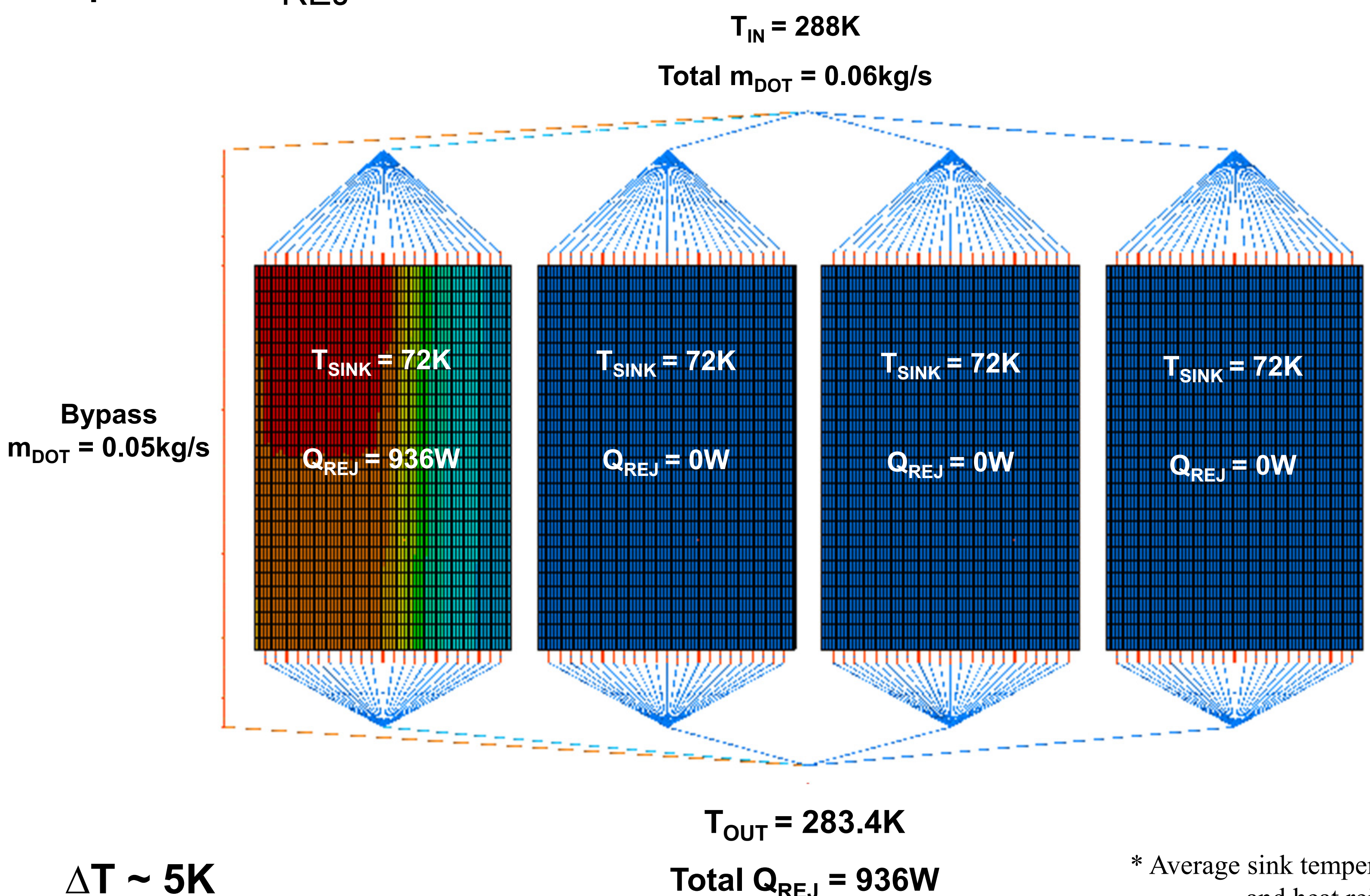


$\Delta T \sim 5K$

* Average sink temperatures and heat rejection

Mission Profile: LEO

Required Q_{REJ} = 936W

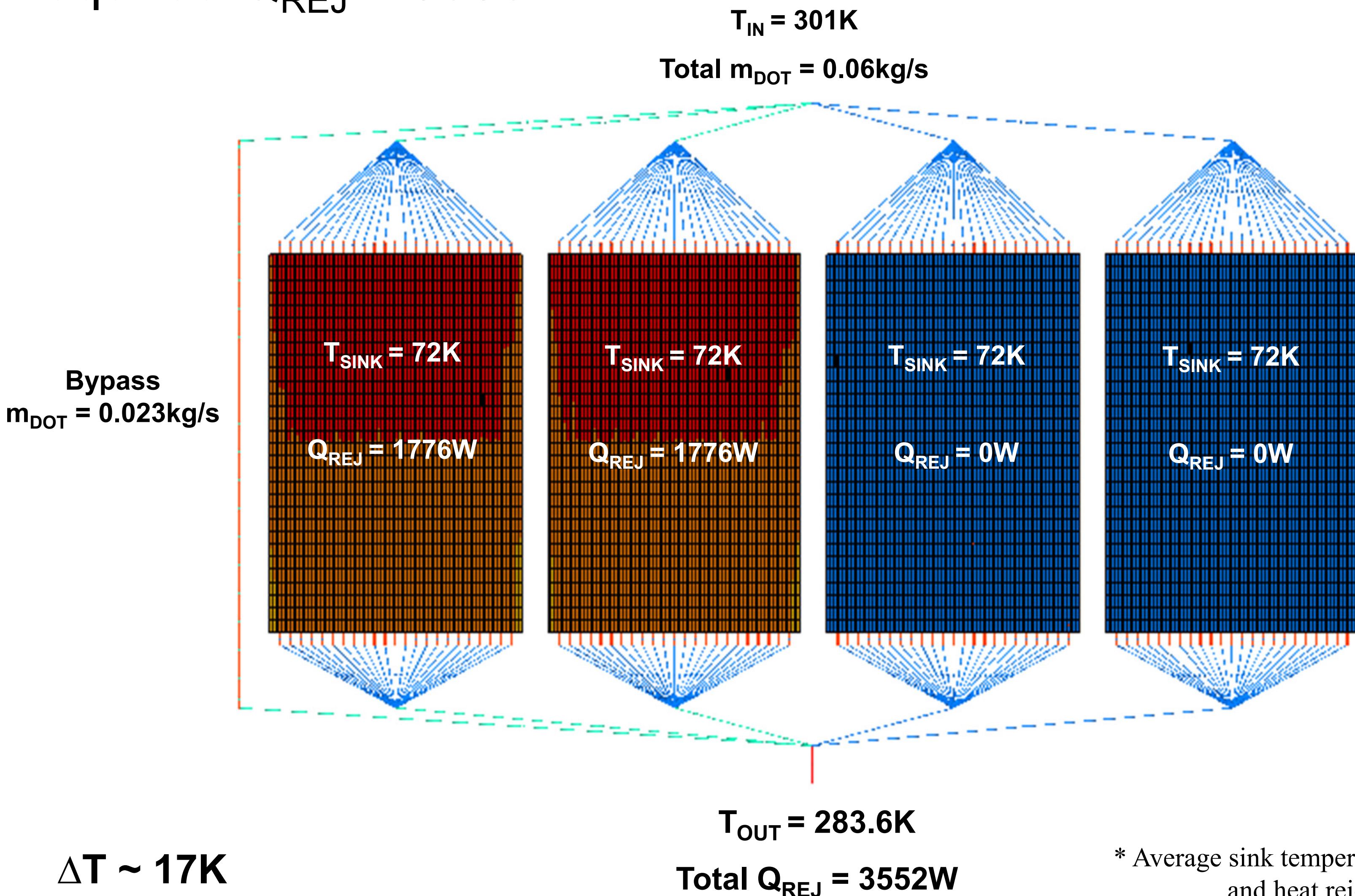


$\Delta T \sim 5K$

* Average sink temperatures and heat rejection

Mission Profile: TLC

Required Q_{REJ} = 3535W

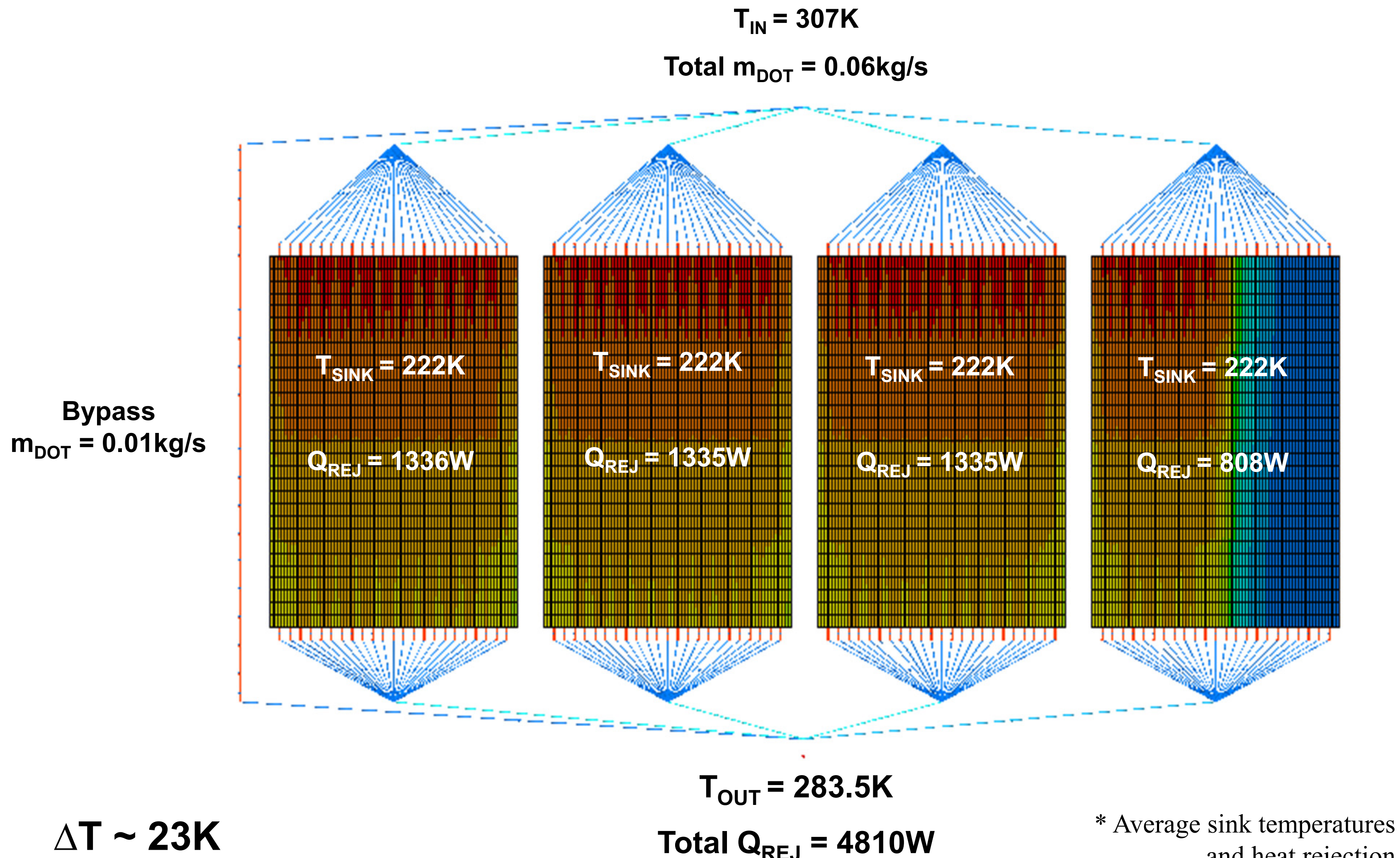


$\Delta T \sim 17K$

* Average sink temperatures and heat rejection

Mission Profile: TLC

Required Q_{REJ} = 4800W

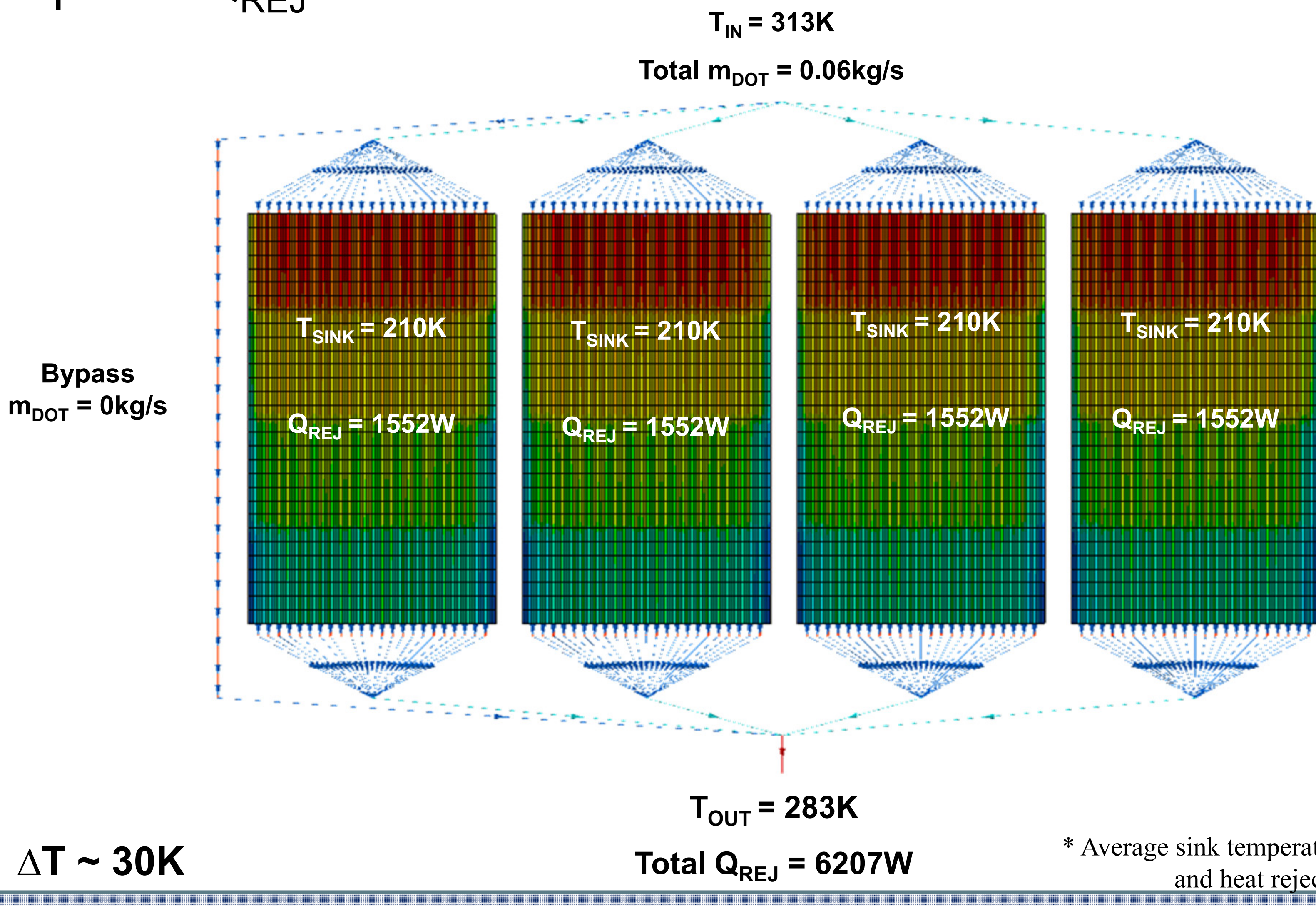


ΔT ~ 23K

* Average sink temperatures and heat rejection

Mission Profile: LSO

Required Q_{REJ} = 6040W



ΔT ~ 30K

* Average sink temperatures and heat rejection

Point Design Metrics

Point design metrics for the digital radiator include:

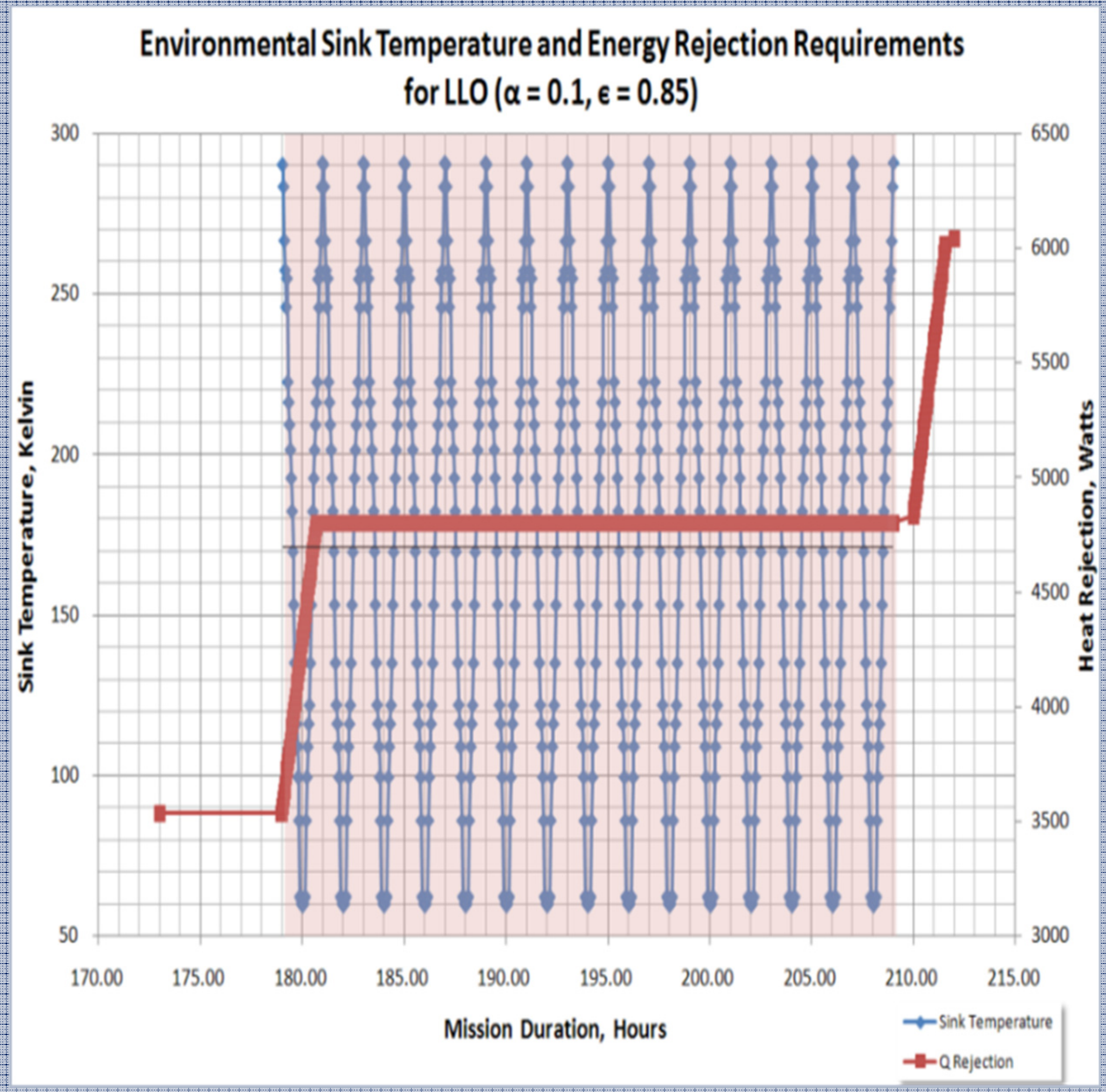
- Mass:
  - Radiator Panel
  - Fluid in the Tubes
  - Mass of the Tube Material
  - Latch Valves to Control Tube Flow*
  - Heaters (Start-Up)
  - Check Valves
  - Evacuation pump*
  - Accumulator*
- Power:
  - Evacuation pump
  - Start-up Heater
- Volume:
  - Available space
- Reliability: High (Latch valves have been used in flight, so also pumps)
- Scalability: Excellent (mass of radiator and valves scale directly, mass of pump and accumulator scales at a reduced levels)
- TRL: 5-6 (currently it is at TRL 4-5)

* Key additional elements in DR compared to Apollo stagnation radiator

Hardware Challenges and Risks

- Several challenges exist in the development of full-scale Digital Radiator for future NASA missions
  - The development of lightweight two-way and three-way latch valves for flight radiator
  - Evaluation of evacuation for smaller diameter tubes (both finned and smooth) for mass savings
  - Obtaining reliable components with the mass estimates used
  - Reliable operation of the completely integrated single panel with the pumps, accumulator, and radiator

Performance Challenge



- LLO will provide a highly variable sink temperature yet require steady heat rejection.
- A sublimator may be implemented to handle the high temperatures but freezing may occur at the low end.
- Knowledge of thermal mass associated with spacecraft required to determine transient performance.
- Heaters, heat exchanger, or alternative fluids may be necessary to handle reaction times.

Design Summary

- Design capable of maintaining outlet temperature throughout mission
- All panels identical and within area constraints
- Two tube evacuations required for mission profile
- Pressure drop across panels less than 10psi
- Multiple configurations (such as various tube quantities per panel) capable of meeting mission profile
- Design for optimal mass and power involves iterations on model trades and laboratory tests